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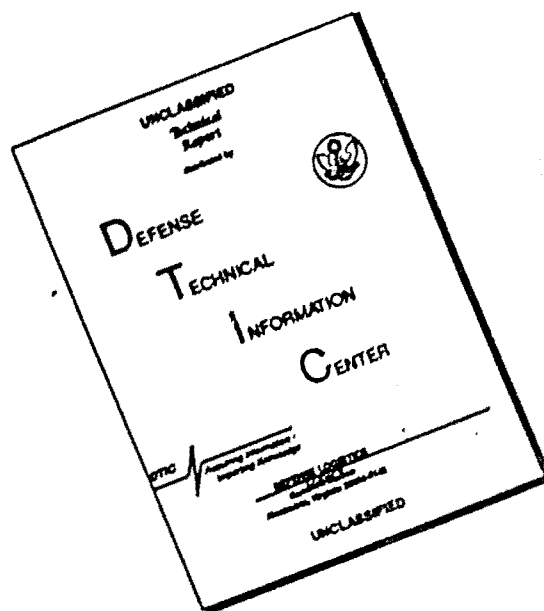
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INFLUENCE OF SELECTED VIBRATIONS UPON SPEECH (RANGE OF 2 CPS - 20 CPS AND RANDOM)

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FOREWORD

This work was done in support of Project 7231, "Biomechanics of Aerospace Operations," Task 723103, "Biological Acoustics in Aerospace Environments." The Biological Acoustics Branch, Biodynamics and Bionics Division, Biophysics Laboratory, 6570th Aerospace Medical Research Laboratories, performed this research between November 1961 and December 1962.

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ABSTRACT

Certain characteristics of speech production are altered during low-frequency vibration (2-20 cps) of the talker. In view of this, speech communication is not at all assured during the vibration and buffeting associated with powered flight, launch, and reentry of manned space flights of the present and the future. Vibrations having the most adverse effects upon man are low-frequency sinusoidal, and random in nature. Standard speech material read by talkers exposed to low-frequency sinusoidal and random vibration conditions was recorded. This material was evaluated both objectively and subjectively in terms of intelligibility, duration, and quality of speech. In experiment I, seated talkers were subjected to vertical, low-frequency sinusoidal vibration. Frequencies of vibration most detrimental to speech production were 6 cps, 8 cps, and 10 cps when speech material was presented in combination with a masking noise. In experiment II, the sitting talkers were exposed to random vibration that simulated the type of conditions experienced in actual space missions and during high-speed, low-altitude flight. No significant differences in speech production were found due to random vibration (0.5 to 8 cps). Speech communication from the space vehicle may be adequate for environments represented by the conditions of this study. However, when these conditions are exceeded by factors, such as higher G levels and higher noise levels at the microphone, a continuous speech communication capability may not exist.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.



J.W. HEIM
Technical Director
Biophysics Laboratory

INFLUENCE OF SELECTED VIBRATIONS UPON SPEECH

(RANGE OF 2 CPS - 20 CPS AND RANDOM)

by

Charles W. Nixon, Ph.D

Henry C. Sommer

INTRODUCTION

Speech communication from the space capsule during cruising phases of the recent orbital flights was, in general, excellent. However, effects of vibratory energy upon the speech of the Astronauts were clearly noticed during launch. This speech was characterized by a tremolo-like quality, which corresponded in some degree to the periodicity of the vibratory energy. One of the most serious threats to efficient speech production during space missions will be vibrations associated with powered flight and the possible oscillations during reentry, particularly of the skip-glide type. During these more critical phases of flight, a continuous speech communication capability from the space vehicle must be maintained. Success or failure of a mission, as well as the personal safety of the passengers, might well depend upon preservation of the communication link, especially in emergency situations. The increased thrust of future propulsive systems, such as for Saturn and Nova, and of other larger boosters, and higher speeds of reentry surely increase rather than reduce this threat to speech communication.

Vibration problems of major importance to crew members of rocket vehicles may be restricted to the low-frequency oscillations and transient accelerations expected during powered flight and reentry (ref. 2). The frequency range below 50 cps requires particular attention with the range from 0.5 cps to 20 cps being somewhat critical for the seated subject. Regions of the body most susceptible to low-frequency vibrations, such as the thorax-abdomen system and the head, are areas also fundamentally important to normal speech production. Stresses that influence or inhibit functions, such as respiration, will also interfere with speech formulation.

The basic problem of speech production in vibration environs is intensified by the presence of high level booster noise. Speech communication in the noise of operational propulsive systems appears to be marginal-to-adequate with present head enclosures and earphones. However, the combined stresses of vibration and noise appear to affect speech efficiency to a greater extent than can be attributed to either single stress.

The influence of vibration and of noise combined with vibration upon speech production was evaluated at sinusoidal frequencies of 10 cps, 20 cps, 30 cps, 40 cps, and 50 cps (ref. 9). Results of this study confirmed earlier estimates concerning the speech of sitting and standing talkers vibrated within the 10 cps to 50 cps frequency range. In general, the greatest deterioration of speech occurred at the lowest vibration frequencies of 10 cps and 20 cps, suggesting future research in this frequency region. Speech recorded at 30 cps, 40 cps, and 50 cps was relatively good speech. Also, intelligibility of vibrated speech decreased by a very small amount. With the addition of masking noise to the vibrated speech, intelligibility was reduced significantly at certain frequencies.

This report describes the second and third in a series of investigations concerning the speech production of vibrated talkers. The first investigation (ref. 9) dealt with the range of vibrations from 10 cps to 50 cps and designated the areas of importance to be examined in the subsequent investigations. The second investigation (Experiment I) of speech concerned the low-frequency sinusoidal vibrations of sitting talkers, and the third investigation (Experiment II) concerned low-frequency random vibration of sitting talkers.

Objective

The object of this research was to further evaluate man's ability to produce speech (1) in sinusoidal vibration environments ranging from 2 cps to 20 cps, and (2) in random vibration environs, which more nearly simulate actual flight conditions. The recorded speech in both experimental conditions was evaluated in combination with a masking noise and without a masking noise.

Approach

To accomplish this objective two separate experiments were conducted. In both experiments certain parameters of speech were observed and analyzed. The first was speaker intelligibility. Regardless of how peculiar or bad speech may sound to a listener, regardless of rate, pitch, or inflection, the listener must understand the complete message transmitted by the talker; this is vital to all stages of a mission. Second, the quality or naturalness of the speech must be considered from the viewpoint of the listeners. Speech that is of poor quality or that sounds unnatural may communicate less effectively than normal speech. Consequently, the speech data collected in these experiments were considered in terms of such factors as intelligibility and naturalness or quality of speech of talkers exposed to mechanical vibration.

EXPERIMENT IProcedure

The speech of talkers vibrated at frequencies ranging from 2 cps to 20 cps was investigated in Experiment I. A mechanical shake table provided the vibration stimuli. Talkers sat in an Air Force aircraft seat mounted on the vibration platform (figure 1). A lap belt and shoulder harness restrained the subject during test. No cushioning or padding was provided in order that the true motion of the table was transferred to the talker with a minimum of change. An accelerometer mounted on the vibration platform provided an indication of the actual vibration exposures experienced by the subjects. Accelerations at the test frequencies were 0.5 G at 6 cps, 0.75 G at 4 cps and 8 cps, and 1.0 G at 2 cps, 10 cps, 12 cps, 14 cps, 16 cps, 18 cps, and 20 cps. These levels were selected by the medical monitor to be the maximum level tolerable for 3 minutes exposure. The acceleration levels were below the subjective tolerance criteria suggested by Ziegenruecker and Magid (ref. 10) and by Mandel and Lowry (ref. 9) for this range of frequencies. Figure 2 shows the magnitude of these exposures relative to some tolerance criteria. Participation in all experimental conditions by a subject would have exceeded the maximum allowable exposure set by the medical monitor. Therefore, subjects were assigned to one of two groups. Each group was exposed to one-half of the experimental conditions. Group I was exposed at 2 cps, 6 cps, 10 cps, 14 cps, and 18 cps, and Group II at 4 cps, 8 cps, 12 cps, 16 cps, and 20 cps. Both groups performed in a control condition of no vibration.



Figure 1 (Left)

Photograph of Talker in Air Force Aircraft
Seat Mounted on the Mechanical Shake
Table

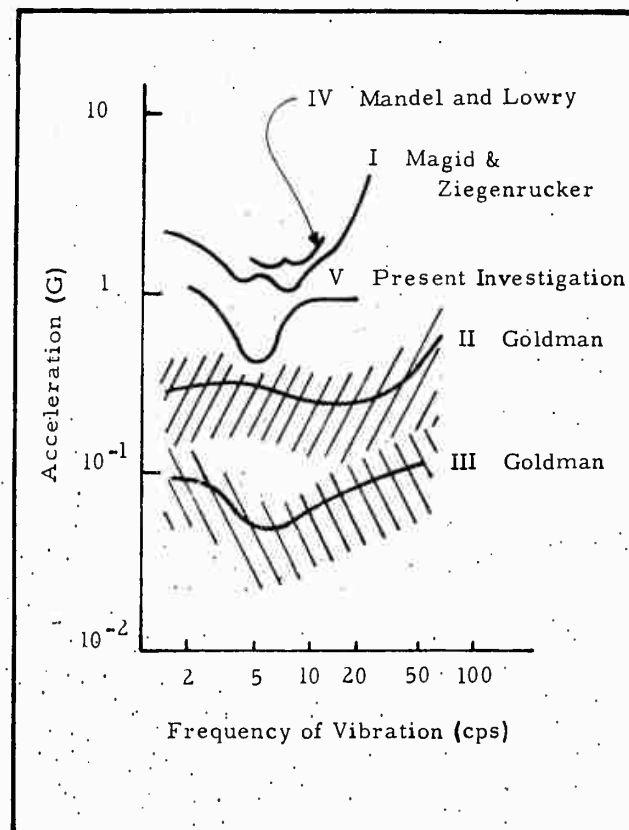


Figure 2. Tolerance Criteria vs Acceleration of Vibrations to which Speakers Were Exposed during Present Study

Average peak accelerations at various frequencies at which:

- I. Talkers (sitting) refused to tolerate further a short exposure to vertical vibrations.
- II. Talkers refused to tolerate it further (5 to 20 minute exposure).
- III. Talkers found it unpleasant (5 to 20 minute exposure).
- IV. Talkers (sitting) refused to tolerate further a short exposure to vertical vibrations.
- V. Talkers (sitting) were exposed during Experiment I.

Curves II and III represent data averaged from seven different sources with talkers sitting, standing, or lying with vibration in the horizontal and in the vertical directions. Curve IV represents a repeat of curve I with the exception that talkers were indoctrinated upon how to breath during vibration.

Talkers wore a standard Air Force P-type flying helmet. A microphone noise shield containing an M-101 noise-cancelling microphone was attached to the helmet and snugly fitted to the face of the talker. Subjects were instructed to read as naturally as possible during the test sessions. The levels at which the speech was recorded ranged between 65 db and 75 db. A speech phrase and intelligibility test words were read from large flash cards held at talker eye level by the experimenter. Each subject practiced reading in this manner before exposure to the six test conditions. Speech was recorded on magnetic tape for later analyses by both objective and subjective means. Talkers monitored the level of their voices by observing a VU (volume unit) meter positioned before them for that purpose. Vibration of the talkers was stopped immediately after all speech materials were recorded or at 3 minutes exposure, whichever occurred first. A 5-minute rest period followed each vibration exposure. Subjects performed only one series of exposure during a 30-day period.

Talkers. Eight members of the Air Force volunteered as talkers for this experiment. All talkers had participated in prior experiments involving exposure to vibration. Talkers were examined by a physician prior to and following each test session. A physician was present at all times during testing. All talkers had acceptable speaking voices with no obvious speech defects or accents.

Listeners. The most valid method for assessing the capabilities of a speech communication system employs speech intelligibility tests and human observers. The primary component of the communication system examined in this investigation was the talker. The extent of his ability to produce intelligible speech during exposure to vibration was observed.

Nine male university students ranging in age from 19 to 22 years were trained to evaluate the vibrated speech in terms of the ASA method mentioned below. A satisfactory level of performance was attained before actual evaluation was begun. All listeners had normal hearing for the audiometric test frequencies from 500 cps to 6000 cps.

A Standard Air Force AIC-10 intercommunication system with ten terminal stations was utilized for the evaluation. The system was calibrated to provide a constant output level at the receivers of each listening station. The terminal headsets were standard H-158 units containing H-143 high sensitivity receivers. A speech audiometer was used as the control unit. The speech produced during vibrations was introduced externally from magnetic tape, whereas the noise used for masking during test originated within the audiometer. This system was considered typical of Air Force operational communications units, and although used in the laboratory, could not be considered as a high fidelity installation.

Several criterion measures were observed to determine if speech production was influenced by exposure of talkers to vibrations below 20 cps. Of particular interest was intelligibility and quality of the speech.

The muzzle did impose a slight restriction upon jaw movement during talking. However, empirically speech intelligibility is not seriously decreased even with severe jaw restriction (ref. 5).

RESULTS AND DISCUSSION

Intelligibility. Intelligibility of talkers exposed to sinusoidal vibrations of 20 cps and below was measured in accordance with the ASA Standard Method of Measurement of Monosyllabic Word Intelligibility (ref. 1). An exception to the standard is noted; that is, the subjects were not thoroughly trained as talkers. Although brief familiarization and practice were provided, talkers were considered untrained.

Mean intelligibility scores are shown in figure 3 as a function of vibration. Sound pressure levels of the speech were (1) 65 db without masking noise and (2) 75 db, 85 db, 95 db, and 105 db at a speech-to-noise ratio of -7.0 db. Both the speech and the masking noise were presented with headsets. The octave band spectrum of the noise at an overall level of 82 db is shown in table I.

Figure 3
Mean Word Intelligibility
Scores for Talkers Exposed
to Low-Frequency Vibration

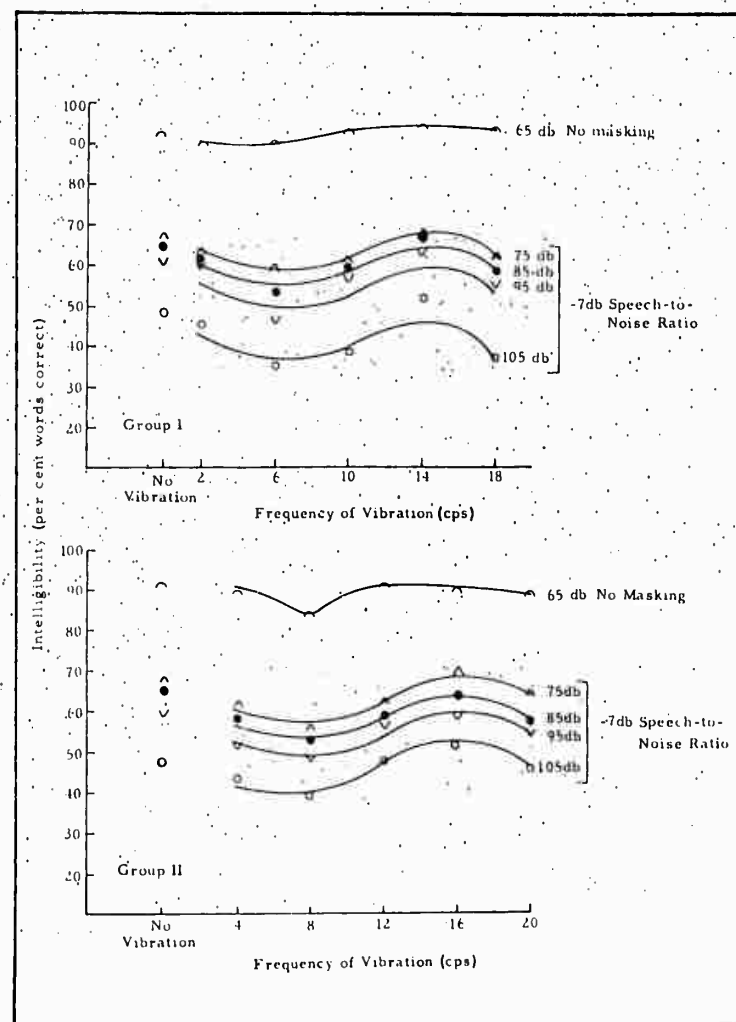


TABLE I

SPECTRUM OF THE MASKING NOISE
PRESENTED OVER THE HEADSETS

<u>Octave Band</u>	<u>Level (db re 0.0002/dyne/cm²)</u>
0A	82
75 - 150	70
150 - 300	70
300 - 600	70
600 - 1200	74
1200 - 2400	76
2400 - 4800	80
4800 - 9600	70

Perception of the monosyllabic words was best for the no vibration condition. The family of curves in figure 3 clearly demonstrates that as frequency of vibration was increased to about 6 cps to 10 cps the speech intelligibility deteriorated. From there intelligibility increased until at 14 cps to 16 cps scores were very close to those for the no vibration condition. Above 16 cps scores began to deteriorate once again. Word intelligibility was lowest at 8 cps for the 75 db and 85 db levels of speech and at 6 cps for the 95 db and 105 db levels. Scores for the 65 db level of vibrated speech showed no differences from the no vibration condition except at a frequency of 8 cps. An 8% reduction in intelligibility was measured for this condition. In general, the speech at 65 db was not influenced by the vibration.

Although these data were analyzed at a speech-to-noise ratio of -7 db, approximate scores for a 0 db speech-to-noise ratio may be estimated. Intelligibility scores in figure 4 were raised by about 25% for the 10 cps vibration condition as the speech-to-noise ratio was increased from -7 db to 0 db. This factor of 25% if applied to the data of figure 3 would raise all scores to values corresponding to 0 db speech-to-noise ratio. A speech-to-noise ratio of -7 db was used for all listening sessions to increase the sensitivity of the intelligibility measures in this application.

A criterion for acceptable performance of a communication system for military operations is an intelligibility score of 70% correct or better with a trained crew of talkers and listeners using the American Standards Association monosyllabic word test (ref. 6). The intelligibility of sentences and standardized phrases and messages used in normal day-to-day operations will be at or near 100% over a system meeting this measure. All conditions required for use of this criterion were satisfied for the data presented in figure 3, except that talkers were not well trained.

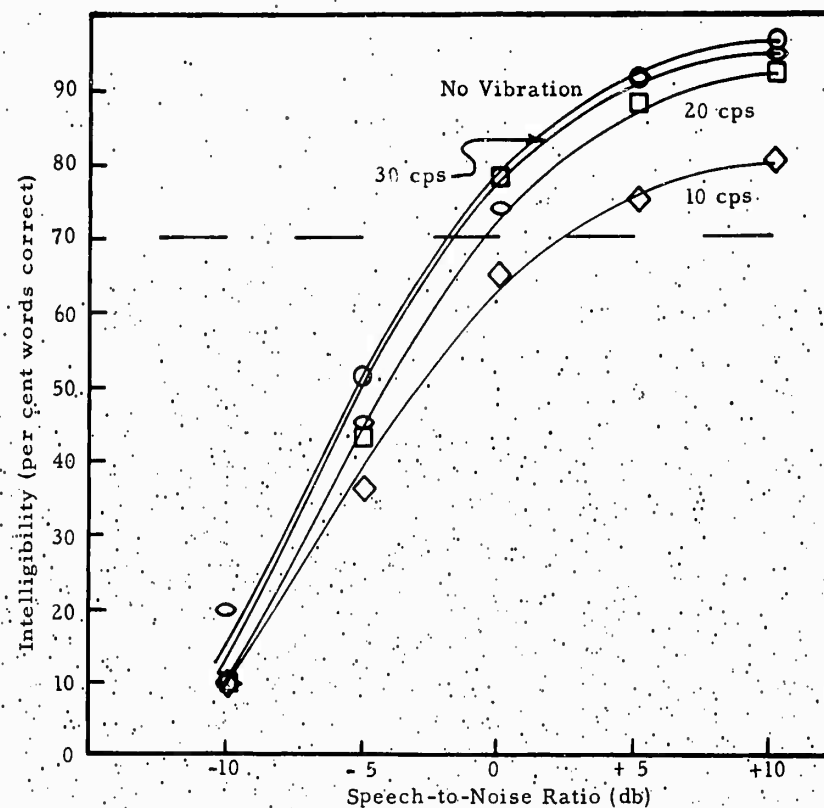


Figure 4. Mean Word Intelligibility Scores for Sitting Subjects at Speech-to-Noise Ratios of -10db, -5db, 0db, +5db, and +10db

On the basis of the 70% criterion, most of the speech communication in noise (-7 db speech-to-noise ratio) represented in this experiment would be inadequate for military operations. However, practical situations rarely exist with such negative speech-to-noise ratios. If these data are adjusted on the basis of the 25% correction of figure 4, only word intelligibility at 4 cps, 6 cps, 8 cps, and 10 cps at 105 db SPL would be inadequate at 0 db speech-to-noise ratio, all other scores would exceed 70%. Intelligibility increases with higher speech-to-noise ratios provided the level of the speech does not exceed 85 db to 90 db. Above these levels overloading and distortion occur in the human auditory system and words are not perceived as well as at more moderate levels. Word intelligibility in the vibration environments ranging from 6 cps to 10 cps was about 10% less than the no vibration data. Efforts to assure a speech communication capability should use this low-frequency range of vibrations as a target area requiring most improvement.

As long as positive speech-to-noise ratios are maintained, adequate speech intelligibility in terms of the talker would be predicted for operational situations represented by these laboratory conditions. In the event of factors or combinations of factors, such as negative speech-to-noise ratio, more intense vibrations than used in this experiment, and speech signals more intense than 85 db to 90 db, talker intelligibility would be less efficient with listeners perceiving something less than the complete message.

The thorax-abdomen system is one of the body subsystems most important to talker intelligibility during exposure to vibrations (ref. 3). During vibration, when the abdominal mass swings down toward the hips and the abdominal wall is stretched outward, the diaphragm is deflected downward and a decrease occurs in chest circumference. As the abdominal contents swing upward, the movements are reversed and the chest wall is expanded. The oscillations of the abdominal mass are coupled with the air oscillations of the mouth-chest system. Maximum responses of the abdominal wall and anterior chest will occur between 5 cps and 11 cps. Vibration of a sitting subject in this frequency range is clearly detected as a modulation of the flow velocity through the mouth. This results from a bellows-like action of the lungs in response to the motion of the abdomen-thorax region. The subject loses some control over his respiration.

Speech produced during excitation of the thorax-abdomen system is clearly amplitude modulated. Results indicate that, in general, amplitude modulated speech was more vulnerable than normal speech to masking by noise. Talkers in noise exposed to vibrations of 6 cps to 10 cps at moderate or intense G levels may apparently be less intelligible than nonvibrated talkers.

Quality of Speech. The J.O. Lee sentences recorded by vibrated talkers were presented to the listening panel for evaluation on a psychological rating scale (ref. 4). Listeners were instructed to rate the speech, not the talker, on an equal-interval scale of from one to seven. A rating of one indicated very good speech, a rating of seven, very bad speech. Listeners had been trained to judge speech samples in this manner and were considered to be experienced.

The mean ratings of the sentence for the experimental conditions are shown in figure 5. Speech during no vibration received the lowest rating (best speech) and speech during 4 cps and 8 cps was highest (poorest speech). The mean rating scores clearly demonstrate a trend as a function of frequency, except for the 6 cps condition. At 6 cps the acceleration level was 0.5 G, while G levels for the other conditions were 0.75 G or 1.0 G. We believe that this single departure from the trend curve of figure 5 is primarily due to the relatively lower acceleration level at 6 cps than for the other conditions. We estimate that an exposure of 6 cps at 0.75 G using the same subjects, etc., would result in a rating of about 3.5. The quality of the vibrated speech was rated poorer than normal speech in all instances, the values of the ratings are about mid-way between good speech (1) and poor speech (7).

During exposure to various low-frequency vibration conditions, the microphone shield tended to shake vigorously against the nose of the subjects. In all such instances, the talkers held the muzzle away from the nose but still over the mouth.

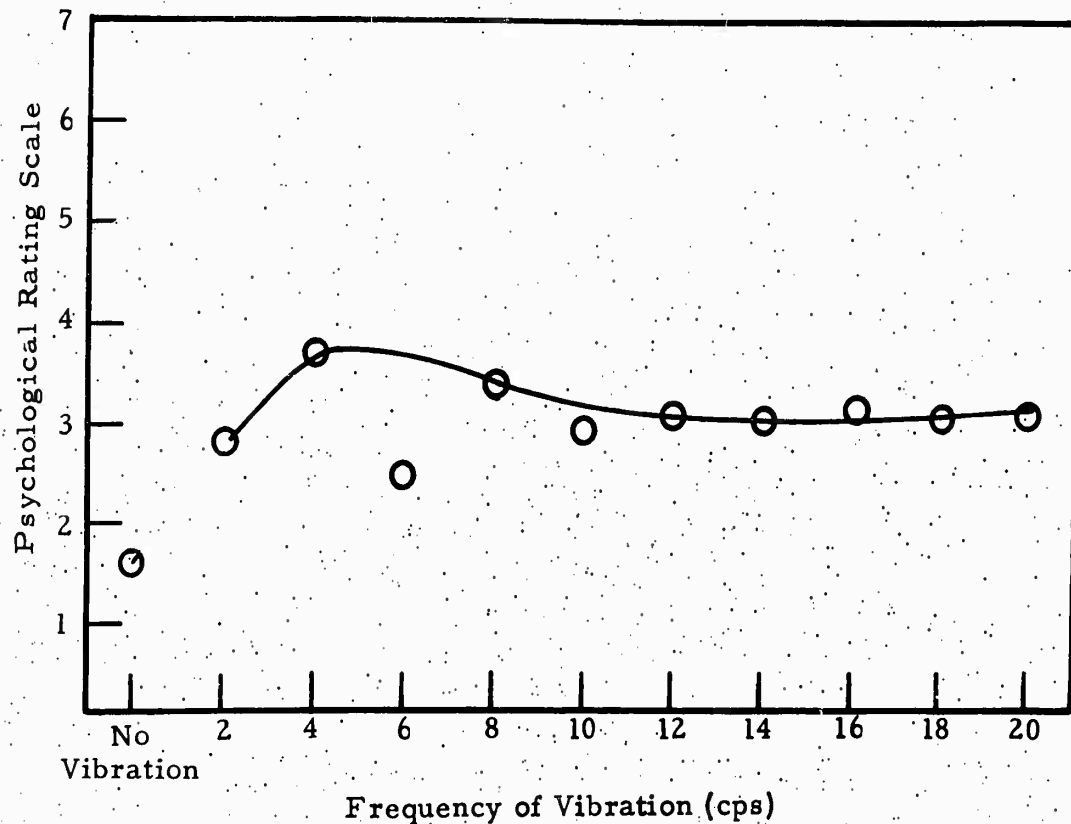


Figure 5: Mean Ratings of J.O. Lee Phrase on An Equal Interval Scale of 1 to 7; 1 Indicates very Good Speech and 7 Indicates very Bad Speech

Although these rating data provide no direct indication of the intelligibility of the sentence, specific listener preferences are indicated. Speech during no vibration was clearly preferred to the vibrated speech. Apparently listeners responded primarily to the amplitude modulation of the speech in making their judgments. The speech of talkers vibrating at low frequencies sounds unnatural and is less preferred by listeners than is normal speech.

EXPERIMENT II

The procedure followed in Experiment I was repeated in Experiment II except for the nature of the stimulus and the criterion measures. The random vibration conditions were attained with the Vertical Accelerator shown in figure 6. This facility was described in complete detail in a report by Lowry and Wolf (ref. 7). The characteristics of the vibration exposure were random within a frequency range of 0.5 cps to 8.0 cps. Acceleration varied about ± 0.5 G from the 0 baseline. Twenty-one talkers recorded speech while being exposed to random vibration and without vibration as a control measure. Subjects wore an H-157 headset-microphone instead of the helmet-noise microphone shield combination. The restraint system consisted of a lap belt and shoulder harness.

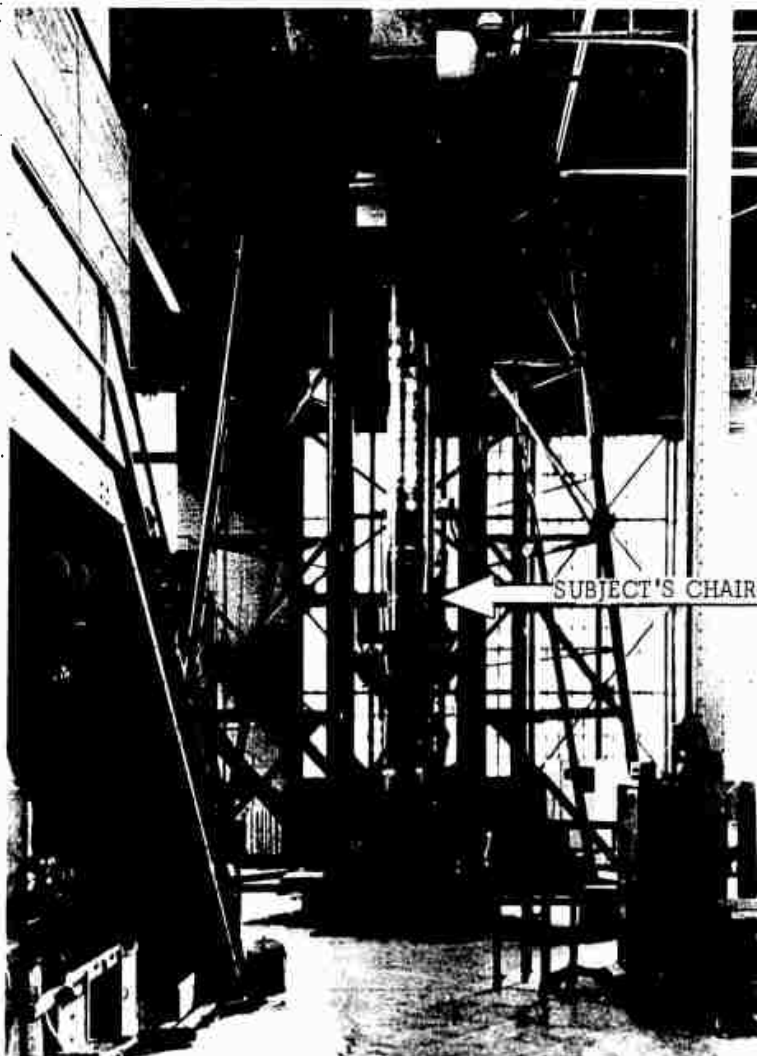


Figure 6. Photograph of Vertical Accelerator

Random acceleration patterns at excursions up to ± 5 feet total excursion can be produced

Three criterion measures were analyzed for influences upon speech of the random vibration. Word intelligibility, duration of vibrated speech, and the solicited subjective reaction of the talkers to their speech were evaluated.

Vibrated speech was presented to the listeners at a sound pressure level of 85 db re 0.0002 ubar with speech-to-noise ratios of -6 db, 0 db, +6 db, and +12 db. Both speech and the masking noise were presented through the headsets. The spectrum of the masking noise was essentially the same as that described in Experiment I.

Word Intelligibility

Mean intelligibility scores for the vibration condition vs. no vibration are shown as a function of speech-to-noise ratio in figure 7. At 0 db and 6 db speech-to-noise ratios, there were essentially no differences in the word intelligibility scores. At -6 db and +12 db speech-to-noise ratios, the vibrated speech was

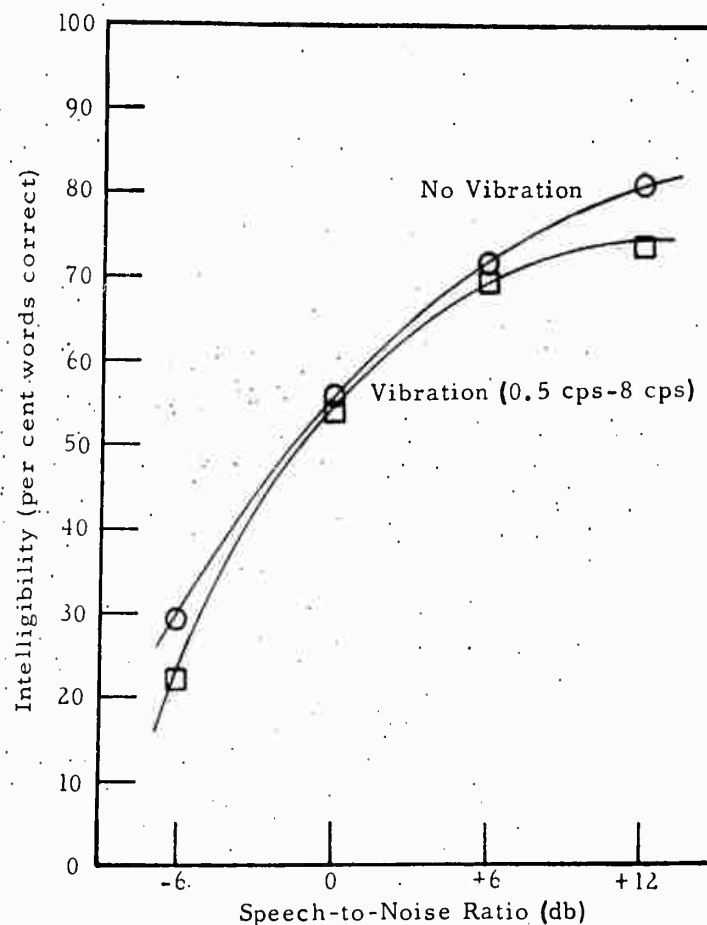


Figure 7. Mean Word Intelligibility Scores for Vibration (0.5cps - 8cps) vs. No Vibration as Perceived with a Speech Level of 85db (re. 0.0002 dyne/cm²) at Speech-to-Noise Ratios of -6db, 0db, +6db, and +12db

slightly less intelligible than the normal speech. Treatment of these data by analyses of variance revealed that differences were not statistically significant. Nevertheless, observation shows that the mean scores for the vibrated speech in no instance exceeded those of the nonvibrated speech. As was noted earlier, acceleration levels in excess of those experienced by talkers in this experiment might result in a greater reduction in intelligibility. The influence of the level of acceleration upon vibrated speech was considered in an experiment recently completed, however, no quantitative data are available at this time. For the conditions examined in this experiment, word intelligibility was not significantly influenced by the random vibration of the talkers.

Duration

Attention was not called to rate of talking at any time during personal communication with the talkers. Instructions were to talk as naturally as possible. The amount of time required for talkers to say a standard sentence was analyzed for variations due to the random vibration.

The mean durations for the sentences recorded during vibration and no vibration were 21.44 seconds and 21.39 seconds respectively. No differences in duration of the standard sentence were measured.

Subjective Response of Talkers

Immediately following the test session, twelve of the twenty-one talkers were informally queried concerning their speech during exposure to the random vibration.

The questions were as follows:

1. Describe your ability to speak during the vibration. Was it very easy, difficult, or very difficult? Comment.
2. How do you think your speech would sound to someone else? Very good, good, fair, poor, very poor? Comment.
3. If you experienced any difficulty at all in talking during the exposure, what seemed to make talking difficult? Comment.

The subjective responses of the talkers to these questions were practically unanimous.

1. Talking was very easy, no noticeable interference or influence.
2. The vibrated speech would sound good to listeners.
3. No subject reported difficulty in talking during vibration.

As discussed in Experiment I, sinusoidal vibration produces a tremolo-like quality of speech that corresponds to the modulation of the air passing through the mouth. Quite different from this rhythmic interruption of speech was the pattern of the interruptions during random vibration. During the random vibration, the flow velocity was interrupted only when the talker experienced a sudden ascent or descent. However, due to the random nature of the stimuli this was not a rhythmic modulation, but instead a randomly occurring modulation. The speech heard during this condition was interrupted for only short instances of time with the period of occurrence at random intervals.

If only G level were increased, the exposure to a random stimuli would have sharper ascent and descent peaks providing more frequent and longer interruptions in speech production, thereby reducing the intelligibility and duration by a corresponding amount. However, due to the performance limitations of the vertical accelerator, it was not possible at this time to increase the G level without risking damage to the accelerator.

To summarize, an analysis of the speech of sitting talkers exposed to random vibrations of 0.5 cps to 8 cps at a level ± 0.5 G from the 0 baseline indicated that; there was no difference between vibrated speech and normal speech when considered in terms of (1) word intelligibility, (2) duration, and (3) subjective evaluation by the talkers of their speech.

SUMMARY

The effects of low-frequency, sinusoidal vibration and random vibration upon speech production of sitting talkers were examined in two series of separate experiments. At the acceleration levels utilized in these experiments: (1) talkers in noise exposed to vibrations of 6 cps to 10 cps were less intelligible than nonvibrated talkers in noise, (2) normal speech (nonvibrated) was clearly preferred to the vibrated speech, which was rated as poor speech, (3) word intelligibility was not significantly influenced by random vibration of sitting talkers (4) there was no difference between duration of normal speech or speech recorded during random vibrations, and (5) no difference between normal and vibrated speech according to subjective evaluation of the speech by the talkers.

RECOMMENDATIONS

The following experiments are suggested as future research in this area: (1) effects of vibration levels upon speech production, (2) effects of vibration upon speech production with talkers in the supine position, (3) hearing during vibration, and (4) pressure suit and restraint effects upon speech production of the vibrated talker, and (5) effects of random vibration at higher G levels upon speech production.

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